Chapter 2

INTRODUCTION AND BACKGROUND

This report presents the results of a multi-laboratory study aimed at quantifying the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States. The stimulus for this study derives from a growing recognition of the link between energy R&D and the nation's ability to respond to international calls to reduce the growth of greenhouse gas emissions. According to a recent report of the Intergovernmental Panel on Climate Change (IPCC), the earth’s surface temperature has increased about 0.2 degrees Celsius per decade since 1975. Further, the IPCC report concluded that “the balance of evidence suggests that there is a discernible human influence on global climate” as the result of activities that contribute to the production of greenhouse gases (IPCC, 1996, p. 5). By preventing heat radiated from the sun-warmed earth from escaping into space, the increased concentration of greenhouse gases in the atmosphere contributes to global warming.

The major greenhouse gases are carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), water vapor (H_2O), and a host of engineered chemicals such as chlorofluorocarbons (CFCs). CO_2 accounts for a majority of recent increases in the heat-trapping capacity of the atmosphere, with worldwide atmospheric concentrations of CO_2 increasing at about 0.5% annually. Anthropogenic CO_2 has resulted in atmospheric CO_2 concentrations that exceed pre-industrial levels by 30%. Of all the human activities that contribute to these increases, fossil fuel combustion is by far the largest, accounting for almost 60% of the greenhouse warming resulting from anthropogenic sources in recent years (NAS, 1992, Table 2.2, p. 8). Energy-efficient, renewable energy, and other low-carbon technologies reduce CO_2 emissions by displacing the need for fossil fuel combustion; hence, this report focuses primarily on this single greenhouse gas. Throughout the report, the potential climate benefits of energy-efficient and low-carbon technologies are quantified in terms of reductions in millions of metric tons of carbon (MtC) emitted.[1]

Analysis by a number of key climate and energy modelers indicates that significant research and development on greenhouse-friendly technologies is essential to achieving meaningful emission-reduction targets at affordable costs. As a result, climate change is becoming a major impetus for energy R&D programs and is likely to grow in importance in the future. By documenting the emissions reductions that past energy-efficiency and renewable energy R&D can deliver by the year 2010, and by describing the potential for future research to reduce carbon emissions even farther, this report is intended to inform a broad public about technology-based approaches to reduce greenhouse gas emissions.

2.1 OBJECTIVES OF THE STUDY

The purposes of this study are threefold:

1. To provide a quantitative assessment of the reduction in energy consumption and carbon emissions that could result by the year 2010 from a vigorous national commitment to accelerate the development and deployment of cost-effective energy-efficient and low-carbon technologies;

2. To document the costs and performance of the technologies that underpin a year 2010 scenario in which substantial energy savings and carbon emissions reductions are achieved;

3. To illustrate the potential for energy-efficiency and renewable energy R&D to lead to further reductions in energy use and carbon emissions by the year 2020.

The report focuses on energy-efficiency and renewable energy R&D. The coverage of additional selected low-carbon end-use and electricity supply options was based in large measure on their perceived potential to contribute significantly to reducing carbon emissions by 2010.

2.2 METHODOLOGY

2.2.1 Overview

To achieve these objectives, we started with the *Annual Energy Outlook 1997* (AEO97) reference case forecasts for the year 2010 (Energy Information Administration, 1996). After thoroughly reviewing these forecasts on a sector-by-sector basis, and working with EIA staff, we chose to accept the EIA "business-as-usual" (BAU) scenario as is for buildings and industry and to modify some of the assumptions and data and produce a new BAU case – not greatly different from the EIA case – for the transportation and the electric utility sectors.

We then assembled existing information on the performance and costs of technologies to increase energy efficiency or, for selected end-uses, to switch from one fuel to another (e.g., from electricity to natural gas for residential end-uses or from gasoline to biofuels for transportation). For the buildings sector, the technology performance and cost data base are extensive. For transportation, the data base – although less fully developed than for buildings – is sufficient for our purposes. For industry, only partial information on technologies and costs is presently available. As a result, the analysis for industry relies primarily on historical relations between energy use and economic activity and much less on explicit technological opportunities. The industrial analysis also includes some examples of industrial low-carbon technologies. The analysis of low-carbon supply technologies in the electricity sector is based on a review of the literature including detailed technology characterizations prepared by DOE in conjunction with its national laboratories and industry.

Next we created scenarios of increased energy efficiency and lower-carbon emissions using the technology data (or, in the industrial sector, historical relations) as a key input. We chose to run three scenarios other than the BAU case. We have termed the first the "efficiency" case. It assumes that the United States increases its emphasis on energy efficiency through enhanced public- and private-sector efforts. The general philosophy of the efficiency case is that it reduces, but does not eliminate, various market barriers and lags to the adoption of cost-effective energy-efficient technology.

The other two cases, dubbed the $25 permit and the $50 permit "high-efficiency/low-carbon" (HE/LC) cases, describe a world in which, as a result of commitments made on a climate treaty or other factors, the nation has embarked on a path to reduce carbon emissions. Both of these cases assume a major effort to reduce carbon emissions through federal policies and programs (including environmental regulatory reform), strengthened state programs, and very active private sector involvement. Both also include a focused national R&D effort to develop and transform markets for low-carbon energy options (e.g., fuel cells for microcogeneration in buildings and advanced turbine systems for combined heat and power in industry). The difference between the two HE/LC cases is in the assumption of a carbon permit price resulting from a domestic trading scheme for carbon emissions with a cap on U.S. emissions (or from equivalent policy measures that increase the price of carbon-based fuels relative to those with less carbon). We assume a domestic permit price of $25 and $50 per tonne of carbon for the two cases. Both of these HE/LC cases include a program of research, development, demonstration and diffusion that is more vigorous than in the efficiency case. In the buildings and industry sectors, the carbon price signal, combined with policies promoting energy efficiency, is believed to trigger most of the additional carbon reductions. In the transportation sector, it is the R&D-driven technology breakthroughs that generate the bulk of the carbon reductions beyond the efficiency case. For the electricity sector, higher prices for carbon-based fuels cause larger shifts from coal to natural gas; for this sector, these same higher relative prices combined with federal and private research, development, and demonstration can bring advanced low-carbon technologies to market.

Although the work focuses on 2010, we also look beyond this date. Here we describe new technologies, materials, processes, manufacturing methods, and other R&D advances that promise to offer significant energy benefits by the year 2020; for this time period, we make no effort to forecast specific levels of market penetration, energy savings, or carbon reductions. Thus, instead of creating scenarios we describe the technological innovations that could enable the continuation of an aggressive pace of decarbonization well into the next quarter century, if appropriate investments in R&D were made.

2.2.2 Time Frame

Analysis for all sectors focuses on two base years (1990 and 1997) against which future progress is benchmarked, and a target year of 2010 for assessing emissions reduction potential. Energy use and emissions for 1990 and 1997 are used to compare future energy consumption and carbon emissions. The report examines a "snapshot" of energy use and carbon emissions, by sector, in 2010. The increased use of energy-efficient technologies combined with the development of new technologies based on past R&D plus an invigorated R&D effort initiated in 2000 are needed to achieve our 2010 scenarios. Intermediate years between 1997 and 2010 are not examined.

We also highlight the likely post-2010 benefits of an intensified investment in energy R&D. This captures the effects of technologies that may not be widely commercial for some years but that could deliver cost-effective energy savings and emissions reductions, if public and privately supported R&D were to accelerate their proof of concept and reduce their developmental risks.

2.2.3 End-Use Efficiency Scenarios

Each of the three end-use sector chapters is consistent in terms of overall approach, scope, and time frame. They each analyze three scenarios for the year 2010: a business-as-usual case, an efficiency case, and a high-efficiency/low-carbon case. (In the integration of this work, we later assess two different HE/LC cases – one with a $25/tonne carbon charge and the other with a $50/tonne carbon charge.) The buildings sector also presents a “frozen efficiency” baseline, for additional comparison purposes. While there is variation in the methodologies used to estimate the energy savings and emission-reduction potential of each sector, the three sector chapters are similar in using a combination of technology analysis and model-based forecasting. Specifically, the buildings and transportation sectors use stock models with technology characteristics and other parameters taken from assessments of individual technologies. The industrial sector forecasts conservation investment behavior based on econometric modeling with industry-specific conservation supply curves as inputs.

All of the scenarios described in this report use the AEO97 forecasts of national economic output as measured by gross domestic product (GDP), which is projected to increase by 1.9% per year through 2015. Similarly, the buildings sector uses the AEO97 forecast of annual growth in residential (1.1%) and commercial (0.9%) floorspace; the industrial sector uses the AEO97 assumption of a 2.1% annual growth rate for manufacturing production; and the transportation sector uses the AEO97 forecast of a 1.5% annual increase in vehicle miles traveled and a 3.7% annual increase in air travel.

The scenarios for each sector also use the AEO97 energy price forecasts. World oil prices are assumed to rise from $17 per barrel in 1995 to $20.4 per barrel (in 1995$) in 2010. In AEO97, natural gas prices increase at annual rates of 1.4%, with larger increases in prices to the industrial, electricity, and transportation sectors offsetting reductions in prices to residential and commercial consumers. Between 1995 and 2010, the average price of electricity is projected to decline by 0.6% a year as a result of competition among electricity suppliers. Electricity prices are forecast to decrease the most for industrial customers and the least for residential customers.

Such macroeconomic and fuel price assumptions strongly influence the rate of penetration of energy-efficient technologies in each sector. Further details regarding these assumptions can be found in EIA (1996c).

Frozen Efficiency Baseline. This case, which is analyzed only for the buildings sector, assumes that energy-consuming equipment and systems existing in the year 1997 remain at the same efficiency until they are retired. This equipment and these systems retire over the 1997-2010 period at a rate based on standard equipment lifetimes. It assumes that all new equipment employed after 1997 remains at the efficiency of new devices in the year 1997. The frozen efficiency baseline provides an upper bound to likely energy demand (under the economic assumptions applied to all the cases), because it ignores all forces leading to higher efficiency of new equipment in the business-as-usual case. It also ignores any retrofits that might take place if there were economic reasons for early retirement of equipment.

This case is presented primarily for heuristic reasons: it describes an easily-understood case in which technology does not change. This is useful for exploring the impacts of technology change. Also, the case is not necessarily divorced from reality: in the era of low energy prices preceding the oil embargo of 1973-74, the energy efficiency of many household, transportation, and industrial technologies changed very little.

Business-as-Usual Case. The business-as-usual (BAU) case represents the best estimate of future energy use given current trends in service demand, stock turnover, and natural progress in the efficiency of new equipment. It assumes that R&D and implementation programs at DOE and EPA continue at more or less current levels, without a significant influx of new funding. It captures likely changes in efficiencies of new equipment over the analysis period. It also allows for some early retirement of equipment where cost savings from new energy-efficient products are high relative to purchase and installation costs, as in some industrial motor and drive systems and commercial lighting retrofits.

To create this scenario, the buildings and industry sectors adopted the AEO97 reference case as their BAU cases. For the transportation sector, we modified AEO97 somewhat. Specifically, the AEO97 reference case forecasts that the efficiency of passenger cars will increase from 27.5 MPG in 1997 to 31.5 MPG in 2010. We believe such improvements are unlikely in the absence of increases in real gasoline prices and hence our BAU case for transportation leaves the MPG performance of light-duty vehicles in 2010 unchanged from 1997 performance.

Efficiency Case. The efficiency case describes the potential for cost-effective, energy-efficient technologies to penetrate the market by the year 2010, given an invigorated public- and private-sector effort to promote energy efficiency through enhanced R&D and market transformation activities. This case assumes that national policy, possibly in combination with exogenous events, leads to an increase in the cost-effectiveness and deployment of energy-efficient technologies. Cost-effectiveness is improved because R&D, in combination with increased deployment efforts, result in declining capital costs. We do not specify the policies or exogenous events that could precipitate such changes. Instead, we examine the potential for technology-based energy and carbon reductions, assuming that significant efforts are undertaken to enhance the attractiveness of these technologies.

To be attractive to manufacturers and consumers, a technology must be cost-effective. Thus, this scenario limits itself to describing the potential for cost-effective technologies to reduce energy use and carbon emissions. A technology is defined as "cost-effective" if it delivers a good or service at equal or lower life-cycle costs relative to current practice.[2] Externalities are not internalized in this definition of cost-effective. An energy-efficient technology may be societally cost-effective, for instance by taking into account its air quality or safety benefits, but not be judged cost-effective by our narrower economic criteria. This scenario reflects the view that "policy options exist that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run" (Arrow et al., 1997).

Compared to the business-as-usual case, the efficiency case assumes (1) better technology and (2) higher penetration rates for energy-efficient and low-carbon technologies.

1. "Better technology" results from an invigorated public- and private-sector investment in R&D such that energy-efficient technologies become more cost-competitive based on current fuel prices. Performance

improvements between 1997 and 2010 are mostly incremental in this scenario, but by 2020 they could be revolutionary.

2. "Higher penetration rates" result from an invigorated set of policies and market transformation programs that reduce market failures and allow markets to operate more efficiently. Through improved information and risk reduction, capital markets for energy-efficiency investments could be strengthened and consumer investment hurdle rates for the purchase of high-efficiency equipment could be lowered.

Despite its assumption of an aggressive public commitment to energy efficiency, this scenario also takes into account real-world experience and program implementation constraints which suggest that it is not reasonable to assume that every consumer will purchase the least-cost, high-efficiency technology option. There are many reasons to expect a shortfall from such a maximum case: capital rationing, imperfect information, misplaced incentives, and the unevenness of supply, installation, and maintenance networks (DOE, 1996b).

High-Efficiency/Low-Carbon Case. The high-efficiency/low-carbon (HE/LC) case assumes a greater commitment to reducing carbon emissions through federal policies and programs, strengthened state programs, and very active private sector involvement. One way to view this case is to see it as an attempt to model a world where an international global warming treaty is negotiated over the next few years and where the outcome for the United States (and other Annex I nations) is to stabilize carbon and other greenhouse gas emissions in 2010 at 1990 levels. The United States pursues those reductions by (1) aggressively instituting federal policies to develop and deploy energy-efficiency and low-carbon technologies, such as increased funding for market transformation and R&D efforts and (2) by issuing tradable emission permits.

In this rendition of the HE/LC case, policies are put into place by 2000 and progressively phased in until they are fully in place by 2010. The permit price for carbon would presumably rise steadily through 2010. Thus, we have multiple factors affecting consumer and business behavior, including the following:

- The recognition that policies to reduce carbon emissions will necessarily follow the signing of an international agreement, including an anticipation of higher relative prices for carbon-based fuels;

- The actual increases over time in the permit price of carbon (which we model as averaging either $25 or $50 per tonne for much of this period);

- Increased federal effort to accelerate R&D and diffusion of low-carbon technologies;

- The development and introduction by other countries of advanced low-carbon technologies; and

- The change in consumer preferences and behavior that would result from an international treaty and national commitment to stabilize greenhouse gases, much like changes in consumer behavior in the aftermath of the oil embargo of 1973-74.

In summary, this scenario for 2010 describes a combination of better technology, "readier" markets, and a price of carbon that results in a significantly increased willingness to manufacture, purchase, and use low-carbon technologies. It represents a vigorous national commitment that goes far beyond current efforts.

2.2.4 Methodological Differences Across Sectors

The operational definitions used to model these scenarios for the individual end-use sectors reflect the above conceptual definitions, but are nevertheless distinct (Table 2.1). These differences are due partly to the modeling approaches used for each sector. They also reflect the authors' sense of what could "drive" significant increases in energy efficiency in each sector. For instance, to achieve a high-efficiency/low-carbon scenario, the transportation analysis postulates a set of technology breakthroughs. The industrial analysis, on the other hand, achieves its high-efficiency/low-carbon scenario by doubling market penetration rates and assuming that energy-efficiency decisions are treated as strategic investments with correspondingly lower hurdle rates.

The sectors also differ in the way that life-cycle costs and benefits are calculated to determine the cost-effectiveness of technologies in their efficiency scenarios.

> The buildings sector employs a 7% real discount rate to value the stream of benefits accruing from an investment. These benefits accumulate throughout the specific operational lifetimes assumed for individual technologies. The efficiency case assumes market penetration of about one-third of the technologies that are cost-effective at a 7% real discount but not adopted in the business-as-usual case. The HE/LC case doubles this penetration.
>
> The industrial sector assumes a capital recovery factor (CRF) of 15%, rather than 33% (which is the BAU assumption). Thus, to be considered cost-effective in this sector, an investment must pay back in no more than approximately seven years.
>
> The transportation sector uses a 7% discount rate, but it is applied only to the first five years of operation, even though the expected lifetime of a vehicle may be much longer. This five-year period is meant to reflect the realities of purchase behavior in this sector, and results in decisions that are based on considerably less than the full life-cycle of benefits.

Table 2.1 Conceptual and Operational Definitions of Scenarios for 2010

Scenario/ Definition	Business-as-Usual (BAU)	Efficiency (EFF)	High-Efficiency/ Low-Carbon (HE/LC)
Conceptual Definition	Best estimate of future energy use given current trends in service demand, stock turnover, and natural progress in the efficiency of new equipment, including advances supported by current public-sector programs; assumes no changes in federal energy or environmental policies.	Potential for cost-effective, energy-efficient technologies to penetrate the market given an invigorated effort to promote energy efficiency through enhanced public and private-sector R&D and market transformation activities.	Optimistic but feasible potential for energy efficiency and low-carbon technology based on a greater commitment to reduce carbon emissions resulting from actions that might include the creation of a market value for carbon of $25 and $50 per tonne.
Operational Definitions:			
Buildings	AEO97 reference case developed using the NEMS model.[a]	35% of the difference in total energy savings between the BAU and cost-effective energy savings potential.[b]	65% of the difference in total energy savings between the BAU and cost-effective energy savings potential.
Industry	AEO97 reference case; LIEF is calibrated to this case and then is modified to produce the two efficiency scenarios.	The capital recovery factor (CRF) for energy-efficiency investment used in LIEF is lowered from 33% to 15%.[c]	The CRF is lowered to 15% and the penetration rates for energy-efficient technology used in the BAU are doubled.
Transportation	AEO97 reference case modified to hold new light-duty vehicle fuel economy constant at current levels.	Assumes earlier introduction of advanced fuel economy technology and adds certain key technologies that are not in the BAU.	Postulates breakthroughs in hybrid vehicle technology, major aerodynamic and engine efficiency gains for commercial aircraft, and other technological achievements.

[a] NEMS = National Energy Modeling System developed by DOE's Energy Information Administration.

[b] The cost-effective energy savings potential is defined as the difference between the energy demand that results from using the most energy-efficient of the cost-effective technology currently available or forecasted to be available by 2010, and the energy demand in 2010 assuming business-as-usual rates of technology change and use in the economy.

[c] LIEF = Long-Term Industrial Energy Forecasting model developed by Argonne National Laboratory and Lawrence Berkeley National Laboratory.

2.2.5 What the Study Does Not Do

This report does not describe the policies that might be implemented to achieve higher penetrations of energy-efficient and low-carbon technologies. (Reviews of a wide range of possible policy options can be found in several recent publications, including OTA (1991), NAS (1992), and DOE (1996b)). Rather, this report highlights the potential performance and impacts of technological developments and transformed markets. The existence of cost-effective technologies is a prerequisite for public policies to work. Without the technologies, policies to reduce greenhouse gas emissions will be very costly. Indeed, this analysis suggests that carbon stabilization could produce net benefits if the nation invests significantly in cost-effective energy-efficiency and low-carbon technologies.

Thus, we believe it is critical to understand the availability of technologies, their performance, and their costs for as many end-uses of energy as possible. Armed with this knowledge, discussion of policies becomes much more meaningful. Without it, such discussion is less likely to lead to good decisions. Thus, we choose to focus this report on the more narrow topic of technologies in the belief that doing a credible job in this area will ultimately further the policy dialogue.

A second reason for focusing on technologies is our belief that insufficient attention has been given to the role of R&D on energy-efficient and low-carbon technologies as a means to deal with climate change and other environmental impacts. If effective energy technologies are not developed, then the cost of reducing greenhouse gas emissions (and other environmental impacts of energy) will be very high.

As in the AEO97 reference case, each of the scenarios is completed at the national level. Thus, regional variations in population and economic activity are not considered, nor are regional differences in fuel price, weather, or air quality and environmental conditions that might create regional niche markets for particular technologies. As a result, our analyses have undoubtedly overlooked the possible development of regional markets for advanced energy technologies. A valuable next step would be to conduct analyses at a finer geographic scale to produce national estimates that reflect such regional variations.

2.3 OVERVIEW OF THE REPORT

The rest of Chapter 2 sets the stage for the remainder of this report. It describes historical energy and carbon trends, both at the national level and by sector, as a backdrop for assessing energy consumption and carbon emission forecasts. It also discusses the government's role in energy R&D, including the rationale for government support and some evidence of past energy-efficiency technology successes that benefited from government sponsorship.

Chapters 3 through 5 address each of the major energy end-use sectors: buildings (Chapter 3), industry (Chapter 4), and transportation (Chapter 5). Four tasks are completed for each sector:

1. Energy scenarios with and without a strong efficiency push, focusing on the year 2010, and including comparisons with the AEO97 projections from the National Energy Modeling System;
2. Documentation of the cost and performance assumptions for individual energy-efficient and low-carbon technologies;
3. Development of three scenarios (business-as-usual, efficiency, and high-efficiency/low-carbon cases) for the year 2010 and an explanation of how the scenarios were developed; and
4. Descriptions of new technologies that could become available in the 2010 to 2020 time period, as the result of R&D over the next two decades.

Each of these chapters is accompanied by appendices that provide detailed documentation of the technology assumptions and the forecasting methodologies used. These are labeled Appendices C (buildings), D (industry), and E (transportation).

Chapter 6 analyzes the electricity sector to forecast the effect of electricity and demand savings in the year 2010 on CO_2 emissions from power plants. It also assesses the impact of a $50/tonne permit price for carbon on the generation mix used by the electricity sector in 2010. The results of these analyses are used in the buildings and industry sector chapters to convert electricity savings into carbon reductions. Results from this chapter reveal the importance of fuel choice for new power plants and fuel switching for existing power plants as determinants of carbon emissions in 2010. Specifically, the cost and magnitude of fuel switching from coal to natural gas for power generation, the possible early retirement of some coal-fired plants, and the upgrading/repowering of existing plants were identified as key issues for Chapter 7.

The possible conversion of coal plants to natural gas combined cycle technologies is analyzed in Chapter 7, as one of many electricity supply-side options for reducing carbon emissions by 2010. Other options are addressed in Chapter 7, albeit more briefly, including renewable electricity technologies, efficiency improvements in generation and T&D, advanced coal technologies, and nuclear plant life extension. The chapter also characterizes the carbon reduction benefits that could accrue by the year 2020 from a sustained renewable energy R&D effort.

2.4 HISTORICAL ENERGY TRENDS

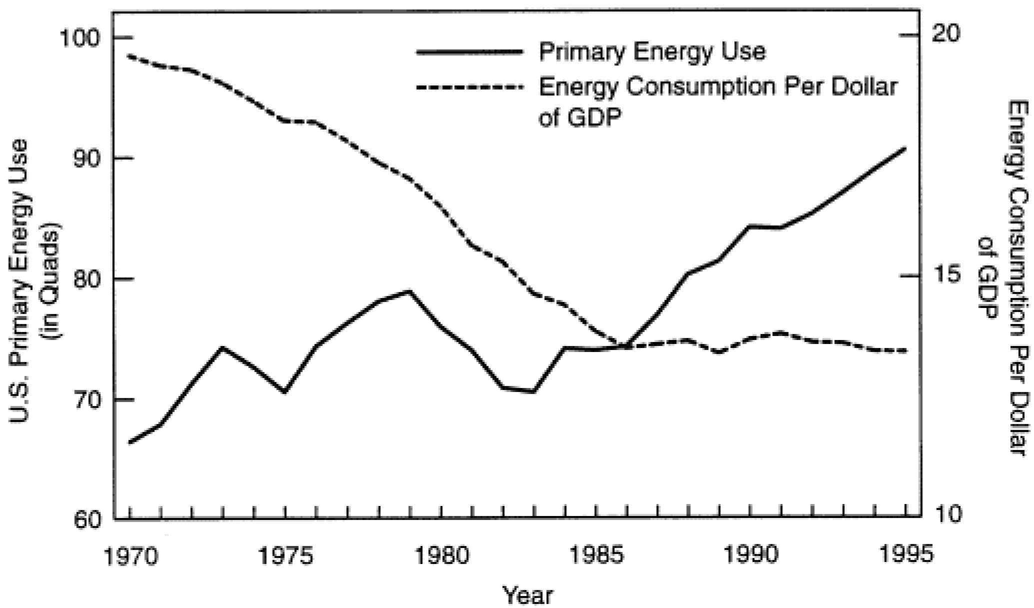
2.4.1 National Trends

In studying historical trends in energy use and carbon emissions, we have chosen to highlight the years 1973, the beginning of rising energy prices to the nation; 1986, the year in which energy prices began a ten-year decline in real terms; 1990, the year generally used as a reference for carbon emissions; and 1997, the first year of our forecast period.

Between 1973 and 1986, the nation's consumption of primary energy froze at about 74 quads – while the GNP grew by 35%.[3] People purchased more fuel-efficient cars and appliances, insulated and caulked their homes, and adjusted thermostats. Businesses retrofitted their buildings with more efficient heating and cooling equipment and installed energy management and control systems. Factories adopted more efficient manufacturing processes and purchased more efficient motors for conveyors, pumps, fans, and compressors. These investments in more efficient technologies were facilitated by higher energy prices and by federal and state policies that were enacted and implemented to promote energy efficiency. About one-third of the freeze in energy use during this period was the result of structural changes such as declines in energy-intensive industry and increases in the service sector; two-thirds was due to increases in energy efficiency (DOE, 1995).

The gains in energy productivity achieved by the U.S. in the two decades following the 1973-74 Arab oil embargo represent one of the great economic success stories of this century. The extent to which the U.S. economy improved its energy productivity can be quantified by examining the relationship between total energy consumption and gross domestic product (GDP), as depicted in Figure 2.1. In Figure 2.1, primary energy use is measured in quads and energy consumption per dollar of GDP is measured in thousands of Btus per 1992$. In 1970, 19.6 thousand Btu of energy were consumed for each dollar of GDP (1992$). By 1995, the energy intensity of the economy had dropped to 13.4 thousand Btu of energy per dollar of GDP (1992$) (EIA, 1996a, p. 17). DOE estimates that the country is saving $150 to $200 billion annually as a result of these improvements.

Figure 2.1 Energy Consumption Per Dollar of Gross Domestic Product: 1973-1995



Starting in 1986, energy prices began their descent in real terms that has continued to the present. As a result, energy demand grew from 74 quads in 1986 to 91 quads in 1995, and it continues to increase. One of the major lessons of the period since 1973 is that the economy will and can respond to energy price changes. In addition to prices, other factors are also important and can slow the decline in conservation activity that otherwise would be expected with declining energy prices. Federal policies, as well as federal, state, and utility programs and consumer preferences for energy-efficient appliances, houses, and cars can increase the purchase and use of energy-efficient products. Technological developments can improve the energy efficiency, reduce the carbon emissions, and often improve the performance of the product. Demand for energy-efficient products and low-carbon energy technologies is also strengthened by factors such as environmental concerns.

2.4.2 Sectoral Trends

Each end-use sector functions differently in the U.S. energy marketplace. One of the reasons for these differences is the differing market structure for delivering new technologies and products in each sector. Residential and commercial building technology is shaped by thousands of building contractors and architectural and engineering firms, whereas transportation technology is in the hands of a few manufacturers.

The principal causes of energy inefficiencies in manufacturing and transportation are not the same as the causes of inefficiencies in homes and office buildings, although there are some similarities (Hirst and Brown, 1990). For example, in the manufacturing sector, energy-efficiency investments are hindered by a preference for investments that increase output compared with investments that reduce operating costs. The cost and relative difficulty of obtaining reliable information often prevents energy-efficient features of buildings from being capitalized into real estate prices. This is partly due to the lack of widely accepted building energy rating systems. These same information gaps do not characterize the transportation sector, which has a well understood labeling system for vehicles, in the form of miles per gallon. Misplaced incentives inhibit energy-efficient investments in each of the sectors. Consumers often must use the energy technologies selected by others. Specialists write product specifications for military purchases that limit access to alternatives. Fleet managers select the vehicles to be used by others. And architects, engineers, and builders have great control over the energy integrity of buildings, even though they do not pay the energy bills. The involvement of intermediaries in the purchase of energy technologies limits the ultimate consumer's role in decision making and leads to an emphasis on first cost rather than life-cycle cost (DOE, 1996b).

The end-use sectors also differ in terms of their ability to respond to changing energy prices. The transportation and residential sectors can respond relatively rapidly to price spikes, through reduced driving and by adjusting thermostat settings, respectively.

The vast differences in the R&D capability of the various sectors also influence their ability to respond quickly to changing energy prices and market signals. The private sector as a whole spends more than $110 billion per year on industrial R&D, dwarfing the federal expenditure on non-defense and non-space technology R&D (National Science Foundation, 1997). Of the private-sector R&D expenditure, the automobile manufacturers stand out – Ford alone spends more than $8 billion per year on R&D. Next comes the rest of the industrial sector. Here, manufacturers account for a majority of the R&D expenditures. Finally, in the buildings sector, the construction industry has virtually no indigenous R&D. The Council on Competitiveness in 1992 estimated that the construction industry spends less than 0.2% of its sales on R&D, far less than other industries, which average 3.5%.

Finally, each of the sectors is distinct in terms of their dynamics and primary societal benefits from improved energy efficiency. Improving the efficiency of transportation is needed to improve air quality and reduce dependence on imported oil. Improving the efficiency of the industrial sector improves economic competitiveness and is often effective in preventing pollution. Opportunities for energy-efficiency improvements are most widespread in the buildings sector because of market barriers in the form of information that is difficult to obtain, energy consumers who do not make purchase decisions on energy-using equipment, etc. Such differences make analysis by end-use sector essential for understanding the U.S. energy, carbon, and innovation picture as a whole.

Table 2.2 presents the primary energy consumed annually by the buildings, industry, and transportation sectors between 1973 and 1997. It shows significant sectoral differences in energy consumption trends. For instance, during the 1973-86 period when the country's primary energy use was steady at 74 quads, energy use in buildings and transportation increased by 2.7 quads and 2.2 quads respectively; industry experienced a compensating decline of 4.9 quads.

Over the entire period from 1973 to 1997, energy use increased in buildings from 24.1 to 33.7 quads (40%); in industry, from 31.5 to 32.6 quads (3.5%); and in transportation, from 18.6 to 25.5 quads (37%). As shown in Table 2.3, the growth in buildings and transportation has been relatively steady, at less than 1% per year from 1973 to 1986, and between 1.3 and 2.9% per year from 1986 to 1997. Growth in energy demand in industry has been much more volatile during the period, showing substantial declines during the period of rising prices (a negative 1.3% annual growth for the 13 years of increasing energy prices), an increase of 2.7% per year from 1986 to 1995, and a 2.9% per year decline from 1995 to 1997.

Table 2.2 Primary Energy Use in Quads: 1973-1997

	1973	1986	1990	1995	1997
Buildings	24.1	26.9	29.4	32.1	33.7
Industry	31.5	26.6	32.1	34.5	32.6
Transportation	18.6	20.8	22.6	24.1	25.5
Total	74.3	74.3	84.2	90.6	91.8

Source: Energy use estimates for 1973-95 come from EIA (1996a, Table 1.1, p. 39). Energy use estimates for 1997 come from EIA (1996c).

Table 2.3 Historical Energy Growth Rates: 1973-1997

	AAGR 1973-97	AAGR 1973-86	AAGR 1986-90	AAGR 1990-95	AAGR 1995-1997
Buildings	1.41%	0.85%	2.25%	1.77%	2.46%
Industry	0.14%	-1.31%	4.81%	1.45%	-2.87%
Transportation	1.32%	0.86%	2.10%	1.29%	2.86%
Total	0.89%	0.0%	3.18%	1.48%	0.66%

AAGR = Average Annual Growth Rate

The growth of carbon emissions during the period roughly follows that of energy demand growth. Table 2.4 shows estimated carbon emissions from 1973 to 1997. Like energy, carbon emissions were flat between 1973 and 1986. The increase in the fraction of coal in the final mix from 17.5% in 1973 to 23.2% in 1986 was offset by the increasing fraction of primary energy from nuclear power, from 0.1% in 1973 to 6.0% in 1986. From 1986 to 1997, carbon emissions grew more slowly than energy consumption. This was a result of an increase in the share of natural gas from 22.5% in 1987 to 25.4% in 1997 and in electricity from nuclear power from 4.5% to 7.2%, combined with a small decrease in coal (23.3% to 22.5%) and a larger decrease in petroleum (43.3% to 39.7%).

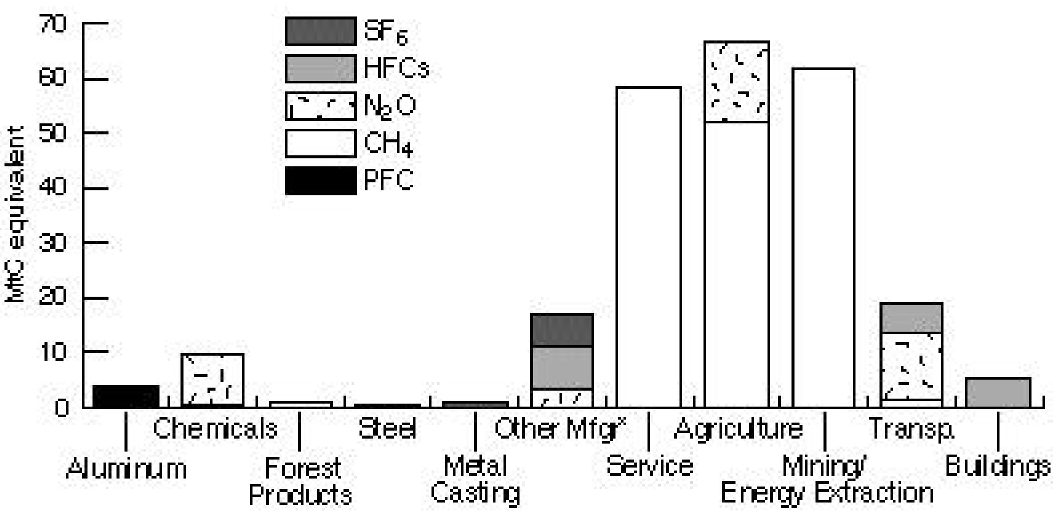
Table 2.4 Carbon Emissions from Fossil Energy Consumption: 1973 to 1997

	1973	1986	1990	1995	1997
Carbon emissions from energy in MtC	1260	1240	1344	1424	1480
	1973-97	1973-86	1986-90	1990-95	1995-97
Average annual growth rates (AAGR) for carbon emissions	0.67	–0.12%	2.03%	1.16%	1.95%

Sources: Carbon emissions estimates for 1990 are from EIA (1996b, Table 6, p. 16), and for 1995 are from EIA (1996b, Table A19, p. 120). Carbon emission estimates for 1973 and 1986 were derived using factors for carbon emissions from combustion of oil, natural gas, and coal for 1990. For 1997, they are from the end-use sector analyses described in Chapters 3 through 5 of this report.

Although non-CO_2 industrial emissions of greenhouse gases are small by weight, they have global warming potentials (GWPs) that range from 21 for methane to 23,900 for sulfur hexafloride (SF_6). Carbon dioxide has a GWP of one by definition. Figure 2.2 shows the relative contribution of these other gases in MtC equivalent. The largest non-CO_2 greenhouse gas contribution is from methane (CH_4), which is responsible for 177.5 MtC equivalent and has a GWP of 21. Next is nitrous oxide (N_2O), which is responsible for 39.1 MtC equivalent and has a GWP of 310. Finally, in 1994, various halocarbons and other engineered chemicals amounted to 29.5 MtC equivalent. These engineered chemicals are a source of concern since their emissions are growing rapidly – and the United States is the major source. SF_6 alone is increasing at a rate of 0.5 MtC equivalent per year (EIA 1996b). Note also that many of these emissions are seen not only in energy-intensive industries but also in "high-tech" and service industries, as shown in Figure 2.2.

Figure 2.2 Non-CO_2 Greenhouse Gas Emissions by End-Use Sector and Industry



* Mainly semiconductors

Source: EIA (1996b)

2.5 THE GOVERNMENT'S ROLE IN ENERGY R&D

2.5.1 Rationale for Government Support

Most people agree that the federal government has a clear and important role in the funding of basic research, and that it should not fund research that the private sector would conduct on its own. Between these two extremes is a wide range of applied technology development and deployment activities where the rationale for federal sponsorship is often unclear.

Economists have identified at least three situations in which the government's role in the R&D process is justified. First is the situation where the potential aggregate benefits of the research are large, but the uncertainties are simply too great for the private sector to shoulder the full research costs. Second is the case where R&D activities will result in benefits that cannot be captured by private entities. Although benefits might accrue to society at large, no single firm can realize enough economic gain to justify the research costs. A recent Council of Economic Advisors report (CEA, 1995) estimated that the private returns from R&D are 20 to 30%, while social returns (including energy and environmental benefits) are 50% or higher. This economic barrier limits the extent to which the private sector can supplant a government role in maintaining nationally beneficial R&D. The third situation occurs when the public sector is the primary consumer of the results of the R&D. This is characteristic, for instance, of much defense and crime prevention research.

Based on these three justifications, the rationale for government support of energy-efficiency and low-carbon technology R&D is strong. Much of this research is both long-term and high-risk and therefore cannot be afforded by private companies despite the possibility of substantial gains in the long run. Examples include high temperature superconductivity, fuel cell vehicles, and building materials with switchable thermal and optical properties. Advances in energy research also offer substantial public benefits that cannot be fully captured by private entities. Specifically, energy-efficiency and low-carbon resources improve energy security by reducing the nation's reliance on foreign sources of oil; they lead to reductions in waste streams; and they reduce greenhouse gas emissions, which contribute to global warming. Finally, it is possible that governments will in the future become the principal purchaser of greenhouse gas reductions as the result of future international agreements. In this case, the third rationale for federal sponsorship of energy R&D will also apply.

Industry's R&D priorities are shifting away from basic and applied research and toward near-term product development and process enhancements. Business spending on applied research has dropped to 15% of overall company R&D spending, while basic research has dropped to just 2%. In addition, corporate investments in energy R&D, in particular, are down significantly (DOE, 1996a, p. 2).

Great potential exists for public-private R&D partnerships to produce scientific breakthroughs and incremental technology enhancements that will produce new and improved products for the marketplace. U.S. industry spends more than $100 billion per year on all types of R&D. The top 20 R&D performing companies all have R&D budgets exceeding $1 billion per year. These expenditures dwarf the U.S. government's energy-related R&D appropriations. If climate mitigation policies reoriented even a tiny fraction of this private-sector expenditure and capability, it could have an enormous impact. One way to reorient private-sector R&D is through industry-government R&D partnerships that involve joint technology roadmapping, collaborative priorities for the development of advanced energy-efficient and low-carbon technologies, and cost-shared R&D.

2.5.2 Past R&D Successes

Some indication of the cost-effectiveness of energy-efficiency R&D can be gleaned from the experiences to date of DOE's Office of Energy Efficiency and Renewable Energy. From fiscal year 1978 through fiscal year 1994, DOE spent a total of about $8 billion on energy-efficiency R&D and related deployment programs. Estimates of the benefits of several dozen projects supported by this funding were published in DOE/SEAB (1995). In response to a detailed review of these estimates by the General Accounting Office in 1995/96, DOE has revised and updated the estimated benefits accruing from five technologies that were developed with DOE support. Altogether, these five technologies alone have resulted in net benefits (i.e., the value of energy saved minus annualized cost premiums for better equipment) of approximately $28 billion (1996$) and annual emissions reductions of 16 MtC equivalent (Table 2.5).[4]

Thus, the value of the energy saved by these five technologies, alone, far exceeds the cost to the taxpayers of DOE's entire energy-efficiency R&D budget over the past two decades. Additional case studies and benefits are documented in Geller and McGaraghan (1996) and DOE/SEAB (1995).

Table 2.5 Cumulative Net Savings and Carbon Reductions from Five Energy-Efficient Technologies Developed with DOE Funding

Energy-Efficient Technology	Net Present Value of Savings Thru 1996 (billions of 1996$)	Annualized Consumer Cost Savings in 1996 (billions of 1996$)	Annual Carbon Reductions in 1996 (MtC equivalent)
Building Design Software	11.0	0.5	8
Refrigerator Compressor	6.0	0.7	3
Electronic Ballast	3.7	1.4	1
Flame Retention Head Oil Burner	5.0	0.5	3
Low-Emissivity Windows	3.0	0.3	1
Totals	28	3.4	16

Note: Savings for the refrigerator compressor and flame retention head oil burner are through 1996 only; the remainder are savings from products in place by the end of 1996 and include estimated energy savings from the product's years in operation beyond 1996.

In addition to funding the development of numerous energy-efficient technologies, including those listed in Table 2.5, DOE has also developed and implemented energy-efficiency standards for equipment and building shells. For example, building efficiency standards became possible as a result of DOE's investment in "building design software" (the first line of Table 2.5). Because of a potential problem with "double-counting", Table 2.5 includes only energy savings achieved *beyond* the savings that resulted from the implementation of minimum energy-efficiency standards for buildings.

Moreover, results recently reported by Elliott et al. (1997) indicate that the total benefits – including both energy and non-energy savings – that accrue from so-called "energy-saving" projects in industry are typically much greater than those from the energy savings alone. In fact, based on numerous case studies, the authors conclude that the average total benefits received from these "energy-saving" projects are close to two to four times the value of the energy savings alone. They also noted that costs and benefits resulting from non-energy ramifications of energy-efficiency projects are often not included in cost/benefit analysis of energy-efficiency projects.

Similarly, Romm and Ervin (1996) describe some of the public health benefits that have resulted from advances in energy-efficient and renewable energy technologies, such as clean air and water. Other collateral benefits include the productivity gains that have accompanied investments in industrial efficiency improvements (Romm, 1994) and the growth in export markets for energy technologies.

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ENDNOTES

[1] In this report, carbon dioxide is measured in carbon units, defined as the weight of the carbon content of carbon dioxide. Carbon dioxide units at full molecular weight (typically, million tonnes of carbon (MtC)) can be converted into carbon units by dividing by 44/12, or 3.67. This approach has been adopted for two reasons: (1) carbon dioxide is most commonly measured in carbon units in the scientific community, in part because it is argued that not all carbon from combustion is, in fact, emitted in the form of carbon dioxide, and (2) carbon units are more convenient for comparisons with data on fuel consumption and carbon sequestration (EIA, 1996b). Note that, in the U.S., a "ton" (sometimes referred to as a "short ton") equals 2000 pounds; a metric ton, or "tonne," equals 1000 kilograms (approximately 2204 pounds).

[2] We evaluate cost-effectiveness from several viewpoints, with real discounts between 7% and 20%. Even with the high discount rates, the efficiency case is cost-effective.

[3] Primary energy use is the chemical energy embodied in fossil fuels (coal, oil and natural gas) or biomass, the potential energy of a water reservoir, the electromagnetic energy of solar radiation, and the energy released in nuclear reactors. For the most part, primary energy is transformed into electricity or fuels such as gasoline, jet fuel, heating oil or charcoal – these, in turn, are referred to as secondary energy. The end-use sectors of the energy system provide energy services such as cooking, illumination, comfortable indoor climate, refrigerated storage, transportation and consumer goods using both primary and secondary energy (NAS, 1992, p. 3)

[4] The net present value (NPV) of cost savings, cumulative through 1996, is calculated as follows:

$$\mathrm{NPV} = \sum_{t\,=\,\text{entry year}}^{\text{end of service}} \left(E_t - P_t \right) e^{0.07(1996 - t)}$$

where: E_t is the value in 1996$ of energy saved in year t

P_t is the annualized cost premium (1996$) of the better product

0.07 is the 7% real interest rate recommended by the Office of Management and Budget

Note that, for future years (1996 - t<0), (E_t - P_t) is discounted by 7% per year; for past years, (E_t - P_t) is raised 7% per year.